Office de la propriété intellectuelle du Canada

Un organisme d'Industrie Canada

Canadian Intellectual Property Office

An Agency of Industry Canada

PCT/CA 00 / 00981

18 OCT 2000 (18 . 10 . 00)

REC'D 02 NOV 2000

WIPO PCT

CA 00/00981

Bureau canadien des brevets

Certification

Canadian Patent Office

Certification

La présente atteste que les documents ci-joints, dont la liste figure ci-dessous, sont des copies authentiques des documents déposés au Bureau des brevets.

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

4

Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,280,996**, on August 26, 1999, by **RICARDO BRUN DEL RE, IZMAIL BATKIN AND WAYNE YOUNG**, for "Electric Field Sensor".

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

S. Grégoire

Agent certificateur/Certifying Officer

October 18, 2000

Date

Canada

(CIPO 68)

OPIC CIPO

ABSTRACT

An electric field sensor employs a capacitive pick-up electrode in a voltage divider network connected to a body emanating an electric field. The pick-up electrode is positioned at a "stand off" location, spaced from intimate contact with the surface of the body. This is equivalent to providing low level capacitive values for the capacitive coupling between the pick-up electrode and the body whose electric field is to be monitored. By avoiding intimate contact, the system is relatively insensitive to variations in the separation gap, reducing sensor motion artifacts in the output signal. Human body-generated electrical signals may be acquired without use of conductive gels and suction-based electrodes, without direct electrical contact to the body, and even through thin layers of clothing.

TITLE: ELECTRIC FIELD SENSOR

FIELD OF THE INVENTION

This invention relates to electric field sensors. A particular application is in the medical field for the detection of body potentials to produce electro-cardiograms (ECG's) and electro-encephalograms (EEG's).

BACKGROUND TO THE INVENTION

The detection of electrical potentials occurring on the human body is the basis for ECG/EEG diagnostic procedures used to assess heart conditions and brain functions. An extensive science has been established on the basis of coupling conductive electrodes to the human body to sense electrical activity that the body is able to generate.

A feature of this technology has been the focus on reducing electrical resistance at the skin/electrode interface. For this purpose ECG electrodes are often used in conjunction with conductive gels and suction cup attachment mechanisms. These arrangements are uncomfortable for the user restrict mobility, and have limited useful life.

Investigations have been made into using capacitive pick-ups to detect electrostatic potentials on the skin of a

patient. Examples in the literature include the text "Introduction to Bio-Electrodes" by Clifford D. Ferris, published by Plenum Press in 1974. In this text the author discusses experiments with insulated, capacitive electrodes based upon the configuration (page 184):

Body surface (skin)/Dielectric/metal/FET.

A shielded single electrode and a two-electrode circuit based on such an electrode are depicted on page 185. Electrode capacitance is reported as 14 uF/cm^2 at page 187.

The text "Electrodes and Measurement of Bio-Electric Events" by L.A. Geddes, published in 1972 by Wiley-Interscience discusses "dry electrodes" at pages 98 - 103. A single electrode circuit based on a insulated anodized electrode and FET transistor is depicted at page 100. A value for capacitive coupling to the subject is reported at page 102 as being 3200 picofarads. Capacitance ranges of 5000-20000 picofarads/cm^2 are referenced at page 102. In particular, this reference reports (page 102):

> "At present there are attempts to provide ultra thin films of insulating materials having high dielectric constants and strengths so that a high electrode-to-subject capacitance will be attained...".

This statement necessarily presumes that such electrodes will be placed in intimate contact with the body of the subject being measured.

In the text "Principles of Applied Biomedical Instrumentation" 2nd edition, L.A. Geddes, L.E. Bater published by Wiley Interscience, 1975, the author observes (at page 217):

> "To obtain an electrode-subject impedance that is a low as possible, every effort is made to obtain a high capacitance by using a very thin dielectric having a high dielectric constant."

In the IEEE Transactions on Bio-Medical Engineering dated October, 1970, Allan Potter and L. Menke report tests on a capacitive electrode having a capacitance of approximately 800 picofarads.

In the IEEE Transactions on Bio-Medical Engineering dated March 1971, C.H. Lagow, K.J. Sladex and P.C. Richardson report (at page 162) values for the capacitance per area of capacitive electrodes, coated with a 175-4550 Angstrom tantalum oxide film, of 14/Vf(micro-farads/cm^2) where sample values for V_f of 10 to 260 volts are referenced.

Accordingly, the prior art has addressed the problem of capacitive dry electrodes in terms of developing high capacitive values for insulated electrodes placed in intimate contact with the surface being monitored. These prior investigative efforts have been focused on maximizing the coupling between the electrode and the skin surface carrying the potential to be detected. This has led to electrodes that

employ thin dielectric surfaces that provide capacitive values between the electrode and skin in contact with the dielectric from about 800-1000 picofarads/cm^2 and much higher.

The results have been only moderately successful. One problem that has arisen is the extensive sensitivity of these capacitive electrodes of prior design to the gap or distance of separation between the electrode and the skin. This sensitivity has presented similar inconveniences to those arising in the use of conductive electrodes, e.g., discomfort and limited mobility due to intimate contact protocols. In particular, prior art systems have never been reported as operating through clothing fabric.

A need exists in the medical field to provide an electrical field sensor that is less demanding in terms of electrode/body coupling. In non-medical fields, useful applications may also arise where the measurement of surface charge is to be effected without contact arising between the charged surface and the electrical sensor, as in the case of measurement over clothing or bandages. The invention herein addresses such needs.

The invention in its general form will first be described, and then its implementation in terms of specific embodiments will be detailed with reference to the drawings following hereafter. These embodiments are intended to demonstrate the principle of the invention, and the manner of

its implementation. The invention in its broadest and more specific forms will then be further described, and defined, in each of the individual claims which conclude this Specification.

SUMMARY OF THE INVENTION

According to the invention in one aspect, an electric field sensor is provided that includes a first pick-up electrode for placement next to a surface whose electrical field is to be sensed through capacitive coupling. This pick-up electrode is not in intimate contact with the body but is positioned at a "stand-off" location that reduces the sensitivity of the measured output to motion artifacts that arises from variations in the separation of the pick-up electrode from the surface of the body being sensed. An insulating layer may be provided over the electrode to separate it from a body by the gap required to achieve the result of the invention. In some cases, signals can be obtained by placing sensors of the invention over protective layers already present on the body.

This electrode functions as a capacitance element located at one end of a voltage divider network that is coupled, either resistively or capacitively at another end to another portion of the surface over which an electrical potential difference exists. The geometry of the arrangement

of the pick-up electrode and the sensed surface are selected to provide the following result. When the electrode is placed adjacent the surface whose field is to be measured, the rate of change in capacitance with a change in the distance between the surface and the pick-up electrode, upon displacement of the electrode towards or away from the surface, is relatively insensitive to such displacement.

The objective in designing the sensor in accordance with this criterion is to ensure that the overall, effective capacitance formed between the pick-up electrode and any surface that may be presented to the outer face of the pick-up electrode will always have a value in the region of a plot of capacitance value versus separation distance wherein, upon displacement of the electrode, the capacitance is varied by a small value which is proportional to the percentage change in the separation distance occurring between the pick-up electrode and the confronted surface.

In particular, and preferably, when the separation of the electrode from the surface varies by 0.1 mm or less, the capacitance value of the coupling between the body and the pick-up electrode varies by less than 50%. More preferably the capacitive value varies by less than 20%.

A useful parameter to characterize body surface inhomogeneities that are encountered in practical situations is the variation in the separation distance, "d", such

variation being designated as "delta-d". A suitable nominal value of delta-d is 0.1 mm. This value represents the thickness of typical protective coatings, dirt layers and surface roughness for many objects. The value delta-d = 0.1 mm is also representative of spatial inhomogeneities in the sensor-to-body separation gap for human skin which are due to human hair or skin irregularities. The same delta-d = 0.1 is approximately equal to temporal variations in sensor-to-body separation which arises from vibrations of the skin or from the compression of clothing layers, when present, between the sensor and the body. For the purposes of this discussion the value delta-d = 0.1 mm is taken as an illustrative value. The value delta-d = 0.1 mm also represents the practical lower-limit of sensor-to-body gap variations in most conditions of interest. Larger values of delta-d are, however, accommodated by the invention.

Given that delta-d gives rise to motion artifacts in the sensed signal which are uncontrollable below a minimum practical limit due to irregularities in the sensed surface, such as curvature and body hair, the required configuration of the invention is achieved by increasing d the separation of the pick-up electrode from the body. This is completely counter-intuitive to the methodologies applied by the prior art experiments with capacitive, "dry" electrodes. Prior art systems employ extremely thin dielectric layers to establish

small values of d and then proceed to place the sensor in intimate contact with the surface of the body being sensed.

The present invention, in one aspect, employs a dielectric layer for the pick-up electrode that ensures that sensing is occurring at a stand-off location which is insensitive to minor motion artifacts and/or surface irregularities.

Other prior art systems employ dielectric layers with extremely high dielectric constants of several hundred or more. However, for the full benefits of the high dielectric constant to be realized, these must be placed in intimate contact with the body being sensed.

For the present invention satisfactory values of dielectric constant have been found in the range 1 to 10, the nature of the dielectric material having little effect on the invention when the pick-up electrodes are placed in `casual' mechanical contact with the body being sensed as in the case of ECG pick-up on hairy skin or over clothing.

Signals arise in the sensor of the invention when the voltage divider network is electrically coupled between a sensed body location and a separate body part that is connected through the body to the surface over which potential or field is being measured. In the case of ECG's, the source of the measured potential difference arises in the intervening body tissue which generates an electric potential within the

body. In the case of extracting ECG signals from the human body, it has been found that a resistive contact coupling to the skin at one end of the voltage divider network may have a resistance value and up to on the order of 500 k ohms resistance. Alternately, coupling to the body can be effected capacitively.

The output signal of the sensor is extracted by measuring the voltage difference across an electrical component in the voltage divider network that is connected to the subject electrical source. This can be done through a high impedance, low capacitance sensing circuit to minimize signal loss. A field effect transistor or operational amplifier having an input impedance of on the order of 10^{12} ohms and an input capacitance of about 3 Picofarads has been found to be satisfactory when the other capacitor(s) in the voltage divider network have values of on the order of 10 Picofarads. Used in conjunction with a pick-up electrode having an area of on the order of one to ten square centimetres, dielectric media having a total effective dielectric constant of 1-10 and a body-to-surface gap distance of on the order of 0.1 to 4 millimetres, signal values of the order of 1 millivolt or less may be detected from the skin surface of the human body.

With this type of sensor configuration useful signals may be obtained with the pick-up electrode separated

from the skin or sensed body by a gap that allows the pick-up to qualify as a "stand-off" electrode. As the gap varies, the strength of the output signal will vary. But by operating the sensor in the capacitance/gap separation region specified by the criterion of the invention, such variations will not detract inordinately from the value of the signals being obtained. In the case of heart monitoring, heart rate and at least the S-T interval can be measured to a satisfactory degree, as well as other intervals, from the virtually complete ECG trace that can be provided by the invention.

As is done in the case of conductive electrode ECG systems, two pick-up sensors may be applied at a spaced separation on the skin. By taking the difference in the output signals from two locations on the body the benefits of common mode noise rejection may be obtained.

Because signals arise in the presence of a connection of a circuit-completing coupling to the body, the detection of signals can be switched on and off by intermittently opening and closing the connection of the divider network to the body. This enables the employment of synchronized detection procedures whereby the sensing network is intermittently connected to the source. Noise signal values detected when the sensors are disabled in the interim may be used to process the sensor outputs to reduce the noise component present therein.

As a further feature of the invention, it has been found that the circuit completing connection to the body need not be made at a location that is remote from where the pick-up electrode is sensing a signal. In fact, it is possible to combine a contacting plate to effect the conductive connection to the body along with a capacitive pick-up sensor in a single module. A further capacitive coupling to the body is required, but this can be effected through a large gap, such as from the wrist to the chest or to an adjacent leg, without the need for any additional physical body connection. This single-location, combined sensor unit can then be placed at a location on the skin and still detect a useful signal, at least at certain locations on the body.

Consequently, a single location pick-up can be used to detect gross signals, such as heart beats, relying on effecting only two direct, physical couplings to the body about a single location.

On this basis, this invention provides a means for detecting electrical fields present on the surface of a body without the use of conductive gels and suction-based appliances. Useful signals may be obtained based on the combination of multiple electrodes assembled in a fixed, preformated array. Thus, multiple electrodes, e.g. 4 or more, may be carried by a clothing-type of support as an array that can be readily donned or removed with minimal inconvenience.

This provides considerable freedom for the tele-monitoring of patients while they engage in daily routines. Freedom from the limitations of conventional tele-monitoring arrangements represents a valuable advance in this field.

The foregoing summarizes the principal features of the invention and some of its optional aspects. The invention may be further understood by the description of the preferred embodiments, in conjunction with the drawings, which now follow.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a combined pictorial/electrical schematic depiction of a single pick-up of the invention in position adjacent to a body whose electrical field is to be sensed. The voltage divider network is capacitively coupled to the body at both ends.

Figure 1B is a conventional electrical schematic corresponding to Figure 1A.

Figure 2A is Figure 1A with the substitution of a resistive, conductive coupling to the body at one end of the voltage divider network. A smaller parallel capacitive coupling remains present as well.

Figure 2B is a conventional electrical schematic corresponding to Figure 2A.

Figure 3 is an electrical schematic for a dual pick-up electrode configuration, based on the pick-up of Figure 1A, with signals being fed to a differential amplifier.

Figure 4 is an expanded electrical schematic of the circuit of Figure 3 with the additional presence of a buffer amplifier and optical coupler to provide electrical isolation.

Figure 5 is a graph showing the change of capacitance for various areas of pick-up electrodes for a range of separation distances.

Figure 6 is a graph showing the percentage change in capacitance for a 0.1 mm change in electrode-to-body gap distance as a function of nominal electrode-to-body gap distance over a range of 0.1 mm to 1.0 mm.

Figure 7 is a plan view of an electrical circuit corresponding to Figure 4 laid-out in a belt to be worn over the chest of a patient.

Figure 8 is a pictorial depiction of the belt of Figure 7 in place over the chest of a patient.

Figure 9 is a pictorial version of a garment worn by a patient that carries four pick-up electrodes.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In Figure 1A a schematic is shown of an electrical sensor system incorporating a pick-up electrode 1 in the form of a flat conductive surface placed adjacent a first location

2 on a body 3 where an electrical signal is to be sensed originating from an electrical signal generator 4 within the body 3 that provides a source voltage Vs. The pick-up electrode 1 develops a capacitive coupling to the body 3 through an intervening dielectric layer separating it from the body 3. This capacitive coupling for the pick-up electrode 1 is represented schematically by the capacitor Cp.

The electrode 1 is connected to the input of an operational amplifier - IC1A, or its equivalent such as a field effect transistor. High resistance diodes D1, connected to the electrode 1 in parallel if high resistance at low forward voltage diodes are used, or in series otherwise, have an effective leakage value of on the order of 10^{12} ohms at low voltage and serve to discharge the electrode and restore proper voltage input levels. Diodes D1, if in parallel format, also serve to protect the operational amplifier IC1A from excessive input voltages.

The output Vo from the operational amplifier IC1A is measured across output resistor R_1 that extends between the output of the operational amplifier IC1A and a reference capacitor C_R that is coupled to the body at a second, separate location 5. This location 5 may be separated from the first location 2 in obtaining conventional ECG signals. The locations 2,5 may also be proximate, e.g. adjacent, at certain body locations and still provide useful signals. In such

arrangement signals are obtained effectively from virtually a single location.

Capacitive coupling C_R is effected by means of an electrode (not shown in Figure 1A) that is separated from the body 3 by a non-conducting material that acts as a dielectric. Conveniently, the case for an on-board battery holder can serve as this electrode, as shown further below.

Inside the body 3, the signal generator 4 is seen as being subject to internal resistance R_B within the body 3.

The circuit of Figure 1A is redrawn as Figure 1B in more conventional form. In Figure 1B, the capacitance C_o arises from the combined input capacitance of the operational amplifier IC1A and the diodes D1. The input resistance of this amplifier is represented by R_o, including the resistive value of the diodes D1. Collectively, the capacitances C_p, C_o, C_R act as a voltage divider network whereby the output voltage V_o is proportional to the source voltage V_s. In Figures 2A and 2B, the coupling to the body 3 at the end of the voltage divider network opposite to the pick-up electrode 1, is effected principally by a direct, conductive contact. The resistance of the interface is indicated by R_R. Necessarily, some slight capacitance coupling is also still present, indicated by C^1_R.

In Figure 5 a graphic plot is depicted of the variation of capacitance C with a variation in the separation

distance d at various separation distances d, based upon the theoretical formula: $C = k.\frac{A}{d}$

where: C is the effective capacitance of, for example C_P,

d is the separation distance of the electrode plate from the body giving rise to the capacitance,

A is the area, or effective area, of the pick-up electrode 1; and

k is a proportionality constant affected by the dielectric material in the separation gap.

Four curves are shown in Figure 5 for pick-up electrodes 1 having surface areas as follows:

$a = 1\ cm^2$ $c = 50\ cm^2$

$b = 10\ cm^2$ $d = 100\ cm^2$

Each capacitance curve can be separated into two important regions: region 6, in which the capacitance chances relatively rapidly with a given change in separation distance; and region 8 in which the capacitance changes relatively slowly with a similar given change in separation distance. These regions are separated on Figure 5 by boundary line 7. For capacitors with an electrode area of around 25 cm^2 and capacitive values below 200 picofarads, region 6 approximately corresponds to the zone with d = 0.1 mm or less; while for such values region 8 approximately corresponds to the values above d = 0.1 mm.

An important implication of Figure 5 is that sensors with capacitance values within regime 6 are very sensitive to small additional changes in the separation distance (delta-d). In contrast, sensors with capacitance values corresponding to region 8 are relatively insensitive to such changes. This is illustrated more succinctly in Figure 6.

In Figure 6, the percentage change in capacitance corresponding to a delta-d = 0.1 mm is graphed as a function of the nominal separation distance d.

Figure 6 is dimensionless along the C axis and applies to all capacitive sensors which obey or approximately obey the relation C=kA/d. According to the invention the capacitive value of the pick-up electrode, and other capacitive sensors when employed, are designed to operate in region 8' of Figure 6, as opposed to region 6' from which it is separated by boundary line 7'.

In this latter regime the capacitance, and hence the output signal is sufficiently insensitive to spatial and temporal body surface variations so as to provide the advantages of signal stability inherent in the invention.

In Figure 3 two pick-ups similar to that of Figure 1A are used to drive a differential amplifier IC3A. The additional electrode 1A is placed at a further location 10, separated from the first and second locations 2,5. Within the

body the signal source V_S may be treated as distributing its potential over the resistors R_B, R'_B, R''_B.

By use of this differential signal detection circuit, common mode noise present in the two pick-up circuits will be eliminated.

Figure 4 shows the circuit of Figure 3 extended by an optical isolator IS01 driven by a buffer operational amplifier IC4A. By mounting these circuits as close as possible to the pick-up electrode 1, interference from ambient 60 Hz electromagnetic signals can be minimized.

In Figure 4, a shielding conductive layer 11 is depicted as overlying the externally-directed side of the circuitry. This layer/structure 11 is preferably connected to the circuit common point. Its role is to exclude effects arising from intruding electro-magnetic signals, e.g. 60Hz, originating in the environment.

In Figure 7 a belt 12 is depicted that carries the circuit of Figure 4. The pick-up electrodes 1 are mounted on a MYLAR(TM) or KAPTON(TM) film 13 that serves both as a spacer and as an insulating dielectric of approximately 0.13 mm thickness. The pick-up electrodes 1 have been measured against a copper plate as providing a capacitance value of 20 picofarads.

It is preferable for the insulating layer to have a thickness which is equal to, or grater than, the size of

surface irregularities of the body being measured, and equal or greater than the variations in the sensor-to-body separation gap.

The belt 12 of Figure 7 has its own on-board power supply in the form of batteries 14. The case 15 of the batteries 14 is connected to circuit common point and serves as an electrode to provide the reference capacitor C_R. A measured value for its capacitance, when placed against a copper plate, of 160 picofarads has been observed with the case 15 coupled to the entire circuit. The substrate for the belt 12 is made of KAPTON(TM) having a thickness of 5 thousandths of an inch. This forms the principal dielectric element for both of the capacitors C_P, C_R. The nature of the dielectric material has little effect on the invention when the pick-up electrodes are located at a sufficient "stand-off" gap from the body.

The shield 11 in the belt 12 of Figure 7 is in the form of a flexible conductive layer, with an insulated undersurface that overlies the circuitry on the outer side portion of the belt 12.

The pick-up electrodes 1 in Figure 4 are held by the substrate 13 of the belt 12, at a fixed, intervening interval. This interval is dimensioned to permit the electrodes 1 to respectively overlie electrical nodes (not shown) on the body 3 of a wearer 16 as shown in Figure 8. The belt 12 is held in

place by tension developed by connectors, e.g. hook-and-loop fastening means, once positioned on the body 3. While a narrow belt 12 is depicted in figure 8, a wider belt or vest 15 could carry three or more electrodes 1 as shown in Figure 9.

An advantage of the invention is that multiple pick-up electrodes can be assembled in a preformatted, fixed array that can be fitted to the body collectively, as a unitary assembly, much as in the manner of donning an article of clothing. This permits a wearer to be "fitted-up" for electrical field measurement in a very short period of time. Data acquisition can readily be suspended and resumed by the simple act of removing and then re-donning the pre-assembled array. No components are consumed in this process.

The electrodes 1 of such a piece of apparel may feed signals to a radio transmitter 19 carried by the wearer 16. In this manner an especially convenient form of tele-monitoring can be achieved.

CONCLUSION

The foregoing has constituted a description of specific embodiments showing how the invention may be applied and put into use. These embodiments are only exemplary. The invention in its broadest, and more specific aspects, is further described and defined in the claims which now follow.

These claims, and the language used therein, are to be understood in terms of the variants of the invention which have been described. They are not to be restricted to such variants, but are to be read as covering the full scope of the invention as is implicit within the invention and the disclosure that has been provided herein.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY ARE CLAIMED AS FOLLOWS:

1. An electric field sensor for detecting an electric field present over a surface having:

(1) a first, pick-up electrode for placement next to a surface whose electrical field is to be sensed through capacitive coupling;

(2) a voltage divider network that is connected at one end to the electrode and at another end to another portion of the surface over which an electrical potential difference exists,

the electrode being placed adjacent the surface whose field is to be measured at a separation distance whereat the change in capacitance arising from a change in the separation distance varies insensitively with displacement of the electrode towards or away from the surface.

2. A sensor as in claim 1 wherein said electrode has a face surface with an area of less than 100 square centimetres, the side of said face surface which is to be placed adjacent the surface whose field is to be measured having an insulative layer positioned thereon of such thickness as to preclude the electrode from providing a capacitive value of over 400 picofarads.

3. A sensor as in claim 1 wherein the overall, effective capacitance formed between the pick-up electrode and said surface has a value in the region of a plot of capacitance value versus separation distance wherein the percentage change in capacitance is less than 50 percent when subjected to a 0.1 mm change in the separation distance occurring between the pick-up electrode and the confronted surface.

4. A sensor as in claim 3 wherein the percentage change in capacitance is less than 20% when a 0.1 mm change in the separation distance occurs.

5. A sensor as in claim 1 wherein the side of said electrode which is to be placed adjacent the surface whose field is to be measured has an insulating layer positioned thereon of the thickness which is equal to or greater than the size of the surface irregularities of the body being measured and the variations in the sensor-to-body separation gap.

6. A sensor as in claim 1 comprising a resistive contact coupling to the surface at the end of the voltage divider network opposite the pick-up electrode has a resistance value of 500 k ohms, or less.

7. A sensor as in claim 1 comprising a capacitive coupling to the surface at the end of the voltage divider network opposite the pick-up electrode.

8. A sensor as in claim 1 comprising a pick-up electrode having an area of between one to 10 square centimetres.

9. A sensor as in claim 1 having a conductive element positioned over the externally-directed side of the sensor to exclude the effects of externally generated electromagnetic signals.

10. A sensor assembly system comprising two pick-up sensors as in claim 1 applied at a spaced separation over the surface and connected to a differential amplifier to obtain the difference in the output signals from two locations on the surface with common mode noise rejection.

11. A sensor assembly comprising multiple sensors each as in claim 1 assembled to locate the pick-up electrodes of each sensor in a fixed, preformated array.

12. A sensor assembly as in claim 11 wherein the electrodes are carried by a clothing-type of support that can be readily donned or removed with minimal inconvenience.

13. A sensor assembly as in claim 12 combined with tele-monitoring means.

14. An electric field sensor for detecting an electric field present over a surface having:

(1) a pick-up electrode for placement next to a surface whose electrical field is to be sensed through capacitive coupling;

(2) a voltage divider network that is connected at one end to the electrode and another end to an electrical coupling means for connection to another portion of the surface over which an electrical potential difference exists,

said electrode having an insulating layer positioned thereon of such thickness as to preclude the electrode from providing a capacitive value of over 400 picofarads.

15. A sensor as in claim 14 wherein the electrode has a face surface with an area of less than 100 square centimetres.

16. A sensor assembly comprising multiple sensors each as in claim 14 assembled to locate the pick-up electrodes of each sensor in a fixed, preformated array.

17. A sensor assembly as in claim 16 wherein the electrodes are carried by a clothing-type of support that can be readily donned or removed with minimal inconvenience.

18. A sensor assembly as in claim 17 combined with tele-monitoring means.

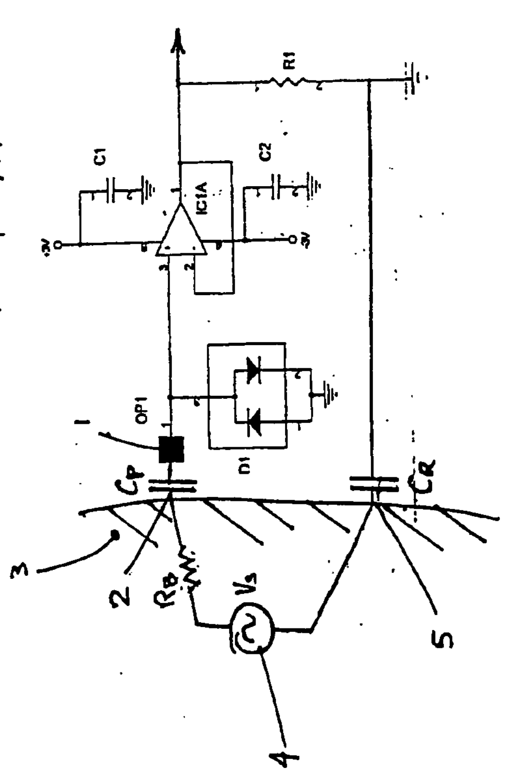


FIG 1A

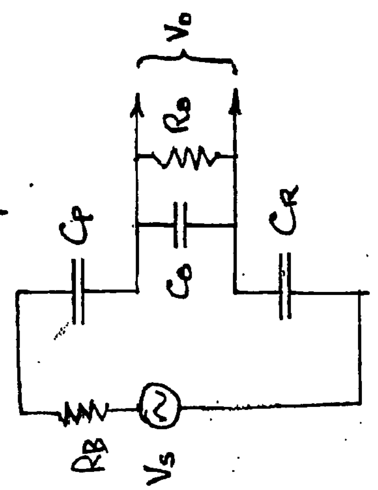


FIG 1B

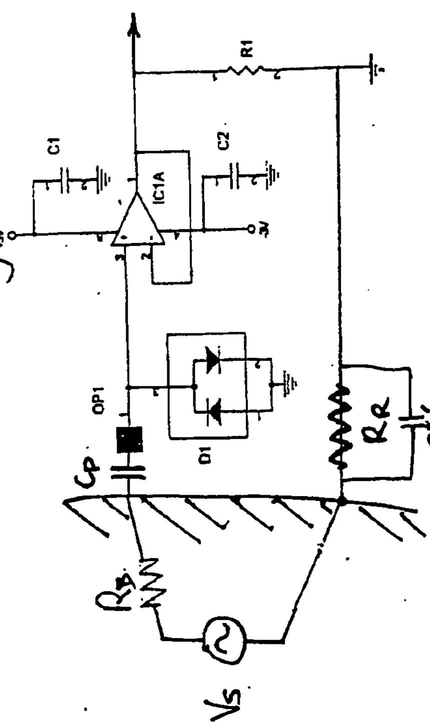


FIG 2A

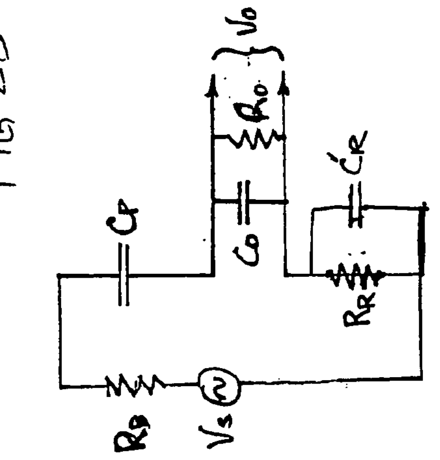


FIG 2B

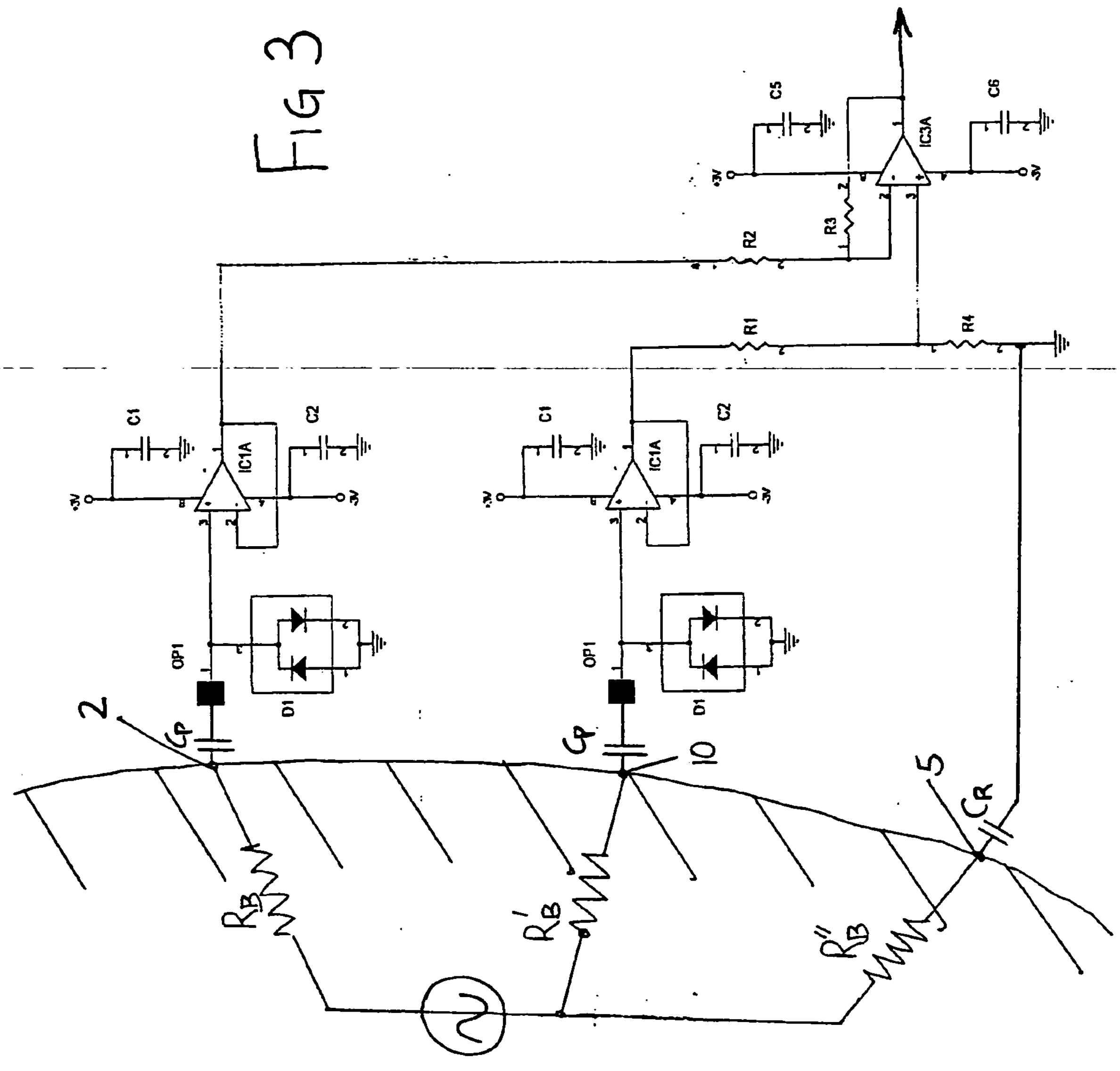


FIG 3

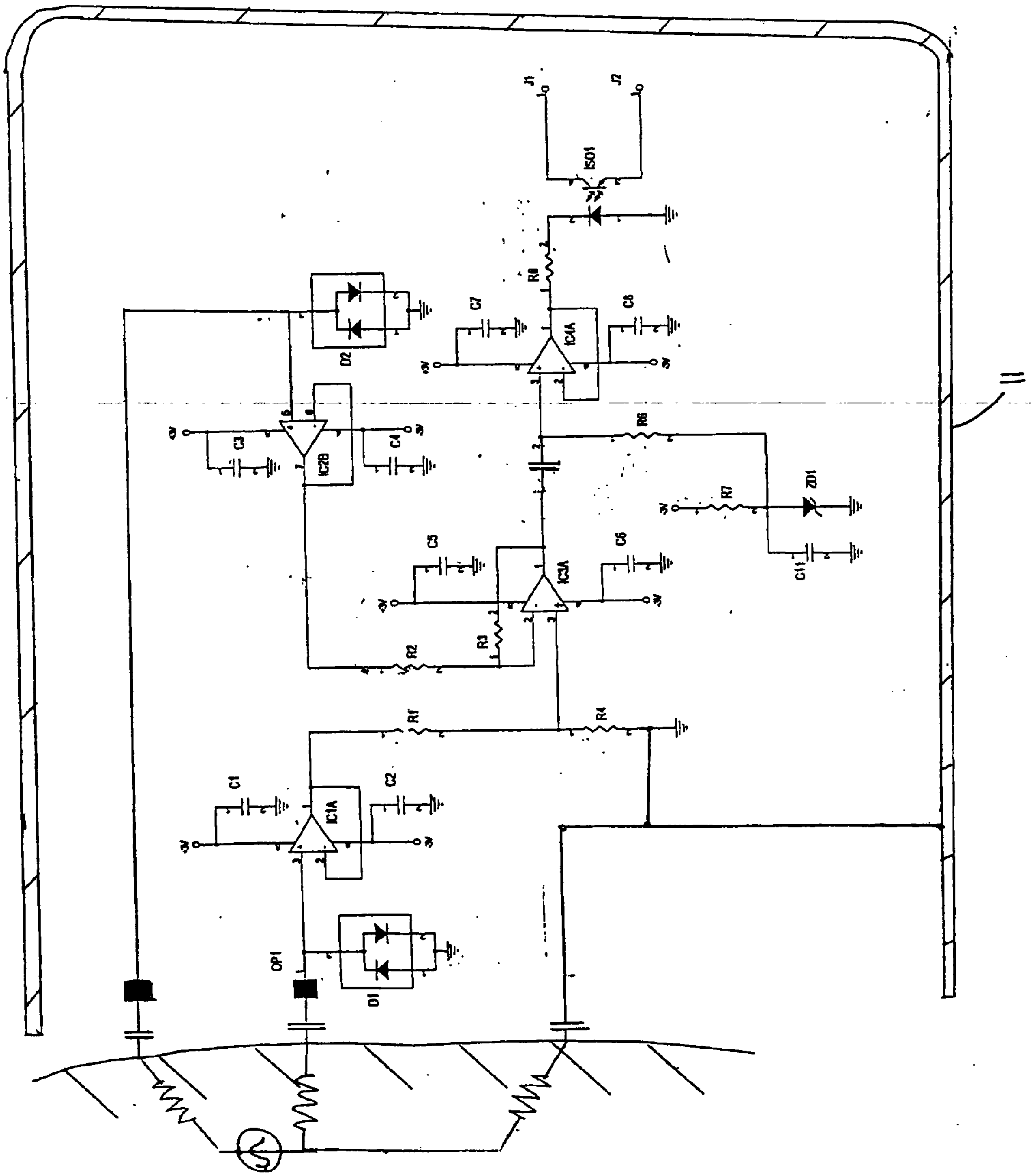
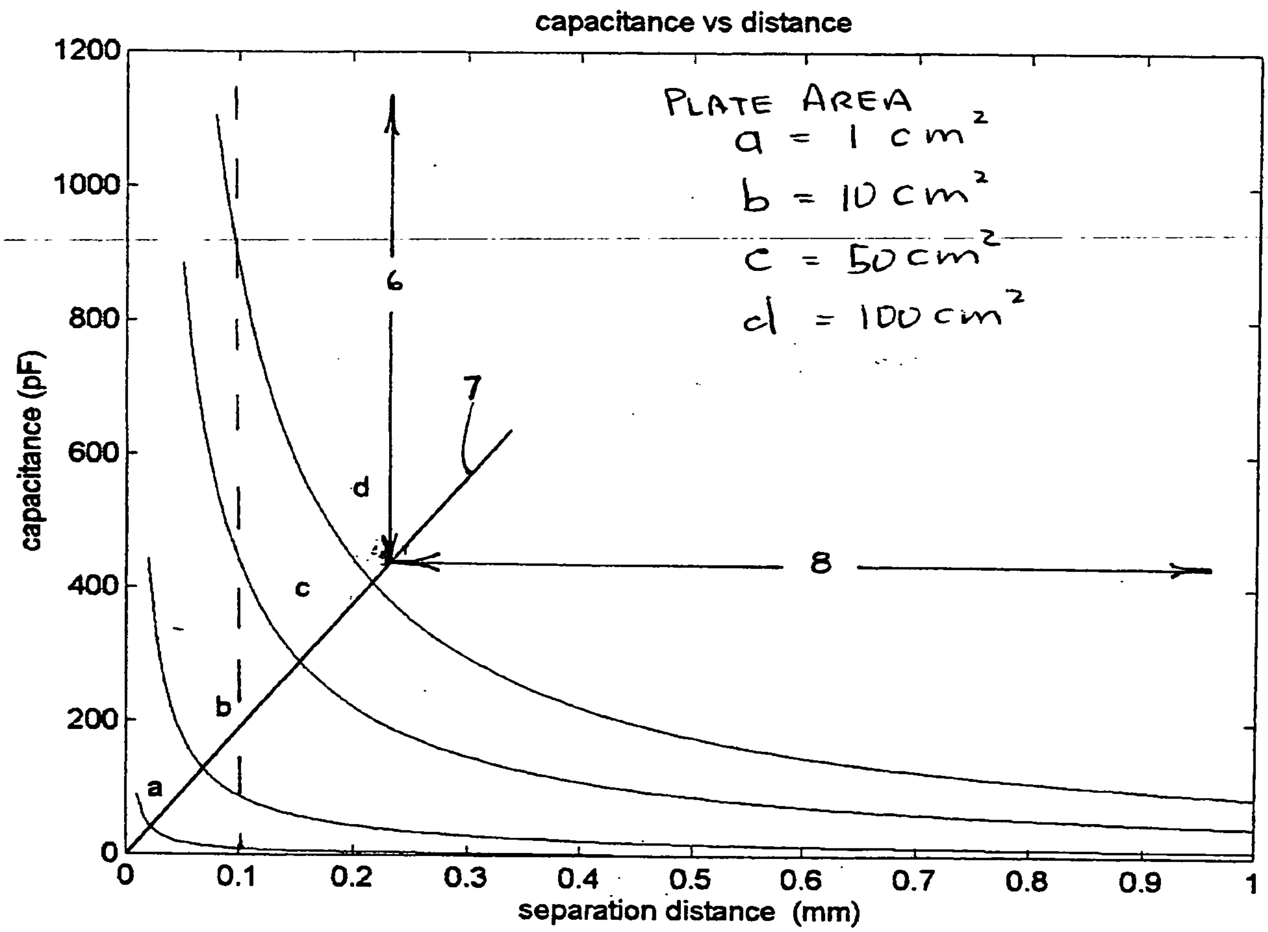

J1
J2
ISO1
R8
C7
C8
IC4A
D2
IC2B
C3
C4
R6
ZD1
R7
C5
C6
IC3A
C11
R3
R2
R1
R4
C1
C2
IC1A
OP1
D1
11

FIG 4

FIG 5


capacitance vs distance
capacitance (pF)
separation distance (mm)
0
200
400
600
800
1000
1200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PLATE AREA
a = 1 cm²
b = 10 cm²
c = 50 cm²
d = 100 cm²
a
b
c
d
6
7
8

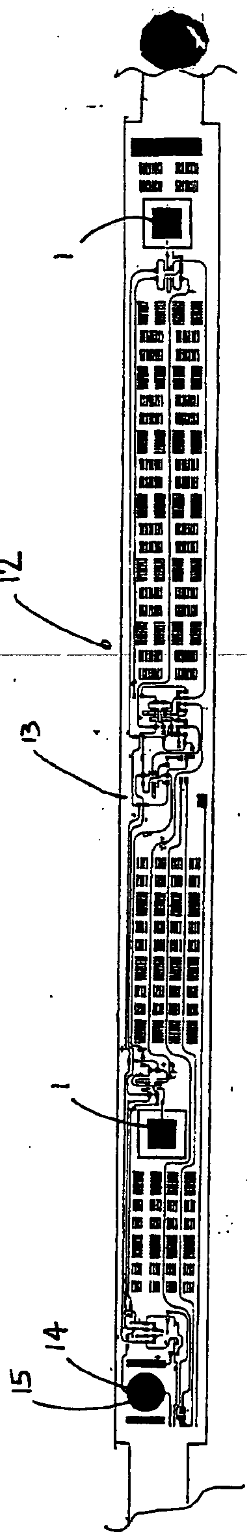


Fig 7

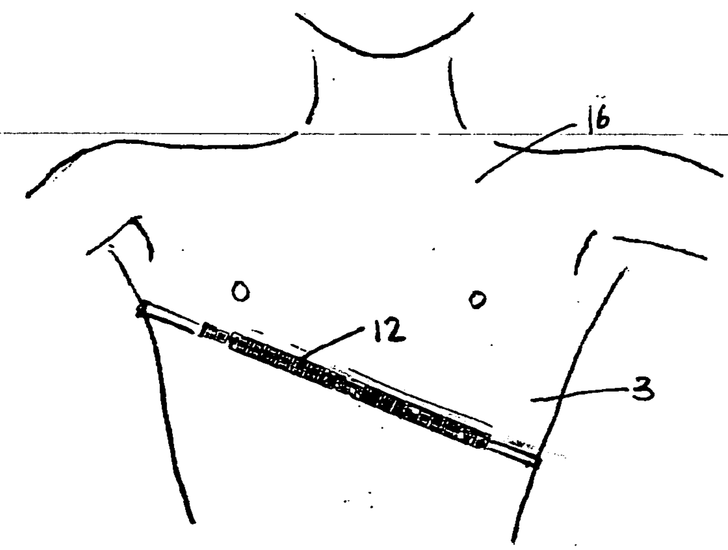


FIG 8

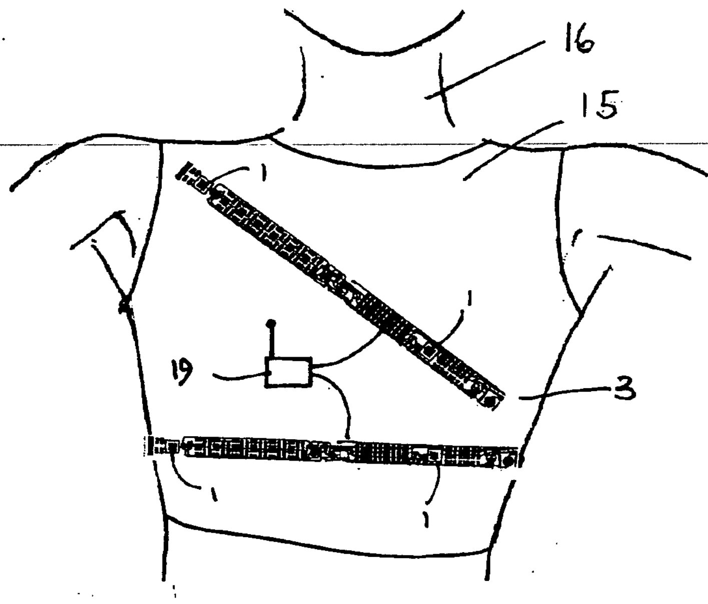


FIG 9

THIS PAGE BLANK (USPTO)